AD-A208 013

Technical Document 1510
April 1989

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Keyword Feedback for Improving Speech Recognition in Command and Control Information-Acquisition Tasks

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ADMINISTRATIVE INFORMATION

Work was performed under DARPA funding by the User Interface Technology Branch, Code 441. This report summarizes work done from November 1986 through April 1987.

Released by
W. T. Rasmussen, Head
Command Support Technology
Division

Under authority of
R. C. Kolb, Head
Command and Control
Department

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
UNCLASSIFIED	
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	Approved for public release; distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
NOSC TD 1510	

6a. NAME OF PERFORMING ORGANIZATION	6b. OFFICE SYMBOL (if applicable)	7a. NAME OF MONITORING ORGANIZATION
Naval Ocean Systems Center		
6c. ADDRESS (City, State and ZIP Code)		7b. ADDRESS (City, State and ZIP Code)
San Diego, CA 92152-5000		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
Defense Advanced Research Projects Agency	DARPA/ISTO	

8c. ADDRESS (City, State and ZIP Code)

1400 Wilson Blvd.
Arlington, VA 22209

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	AGENCY ACCESSION NO.
0601101E	CE27449A		

11. TITLE (include Security Classification)

KEYWORD FEEDBACK FOR IMPROVING SPEECH RECOGNITION IN COMMAND AND CONTROL INFORMATION-ACQUISITION TASKS

12. PERSONAL AUTHOR(S)

Stephen W. Nunn

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Nov 1986 TO Apr 1987	April 1989	23

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

speech recognition
keyword spotting
information acquisition
natural language

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report addresses a number of important issues involving the implementation of continuous speech recognition for information-acquisition tasks. The following questions are addressed:

1. For a restricted information acquisition task such as database query, what can be considered "natural" speech?
2. How can the syntax be constrained to improve accuracy but at the same time still allow natural speech?
3. How effectively can feedback be used to shape or influence the user's speech? Can the user adapt to a limited vocabulary and restricted syntax?
4. For an appropriate task, can a continuous speech recognizer configured as a word spotter be used to partially remove syntax restrictions?

An information acquisition experiment is described. Results are presented and user interaction and reaction are discussed. (AW)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	UNCLASSIFIED

22a. NAME OF RESPONSIBLE PERSON	22b. TELEPHONE (include Area Code)	22c. OFFICE SYMBOL
Stephen W. Nunn	(619) 553-3654	Code 441

DD FORM 1473, 84 JAN

83 APR EDITION MAY BE USED UNTIL EXHAUSTED
ALL OTHER EDITIONS ARE OBSOLETE

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CONTENTS

INTRODUCTION

Our objective in the Speech Technology Group of the User Interface Technology Branch at the Naval Ocean Systems Center (NOSC) in San Diego is to apply speech technology to naval command and control systems. By employing data bases and expert systems to aid in decision making, naval command and control systems are becoming more complex and sophisticated. The design of man–machine interfaces to these systems is critical to user acceptance and functionality. We believe that the use of speech recognition in many of these systems is not only possible, but vital to shipboard operations.

Naval command and control operations present a number of technological problems for speech-recognition systems. Such problems include high or variable background noise environments, moderate stress situations, and the need for high accuracy. It is therefore essential in naval applications to develop speech-recognition interfaces that do not require extensive training, are relatively easy to operate, and are robust.

Naval personnel are required to change stations and perform different functions frequently. Their skill level and familiarity with systems can vary greatly. Each system has its own operating commands and characteristics that must be known before it can be operated. Speech recognition could provide a greatly needed user-friendly interface to these systems that would only require the user to know what kinds of functions the system is capable of performing. Such an interface would greatly reduce the amount of training the user would need to communicate with the system.

In summary, we are driven by the following requirements:

1. Relatively easy system training and use.
2. Robustness to environmental background noise and moderate stress situations.
3. High accuracy.
4. Real-time response.
5. A user-friendly interface that requires minimal knowledge of internal system operation. Ideally the user should only need to know what kind of functions the system is capable of performing in system control operations or what kind of information is available for information acquisition tasks.

One of the most critical command and control user interfaces is the access of database and expert system information. Much time and effort have been spent on the development of extensive real-time databases. We feel that these systems may be little-used or even rejected if the user is required to learn a special language for communicating with each system.

The focus of this paper is two-fold: First, the application of speech recognition in limited command and control tasks requiring the access of database information, and second, an approach to the speech-recognition problem based on keyword-

spotting concepts that can potentially meet speech-recognition requirements in command and control operations.

BACKGROUND

QUERY LANGUAGE

In considering the use of speech recognition for the access of a database, it is of some benefit to examine issues which have arisen with traditional database access using a keyboard.

There has been considerable debate over the issue of which query language is best—a formal query language having a very constrained syntax and vocabulary, or a natural query language that is relatively unconstrained.

Ogden and Brooks (1983) provide a thorough comparison of formula and natural language. Formal query languages have the advantage of having a constrained language which teaches a concise and unambiguous way of communicating with the computer. However, there are a number of disadvantages in using formal query languages. These languages require the user to have an explicit model of the database, i.e., all database attributes and their relationships must be known. Extensive training is required to learn this model and the constraints of the language. Even after training, errors are often made in spelling, syntax, and punctuation. Formal language queries can also be overly verbose and complicated. In many cases, there is usually a more concise way of asking a question with a natural language.

There are a number of advantages to using natural query languages (Ogden and Brooks). More people would be able to access database information if they could use their own natural language. Natural language also eliminates the need to remember a great deal of notation that is irrelevant to the problem and detracts from the user's ability to concentrate on the problem (Ehrenreich, 1981). In addition, users need only describe the data they want retrieved and do not have to be concerned about how that data is retrieved.

However, natural-language interaction is not always the optimal solution. Natural query languages have a number of disadvantages. Training is still required for users to learn the constraints of the language, and even with training, users often do not understand hidden constraints and sometimes ask illegal queries. The inherent ambiguity of the English language can also cause problems.

The arguments for and against the use of natural language with speech recognition are similar to those for and against the use of a keyboard. However, the issue of understanding the constraints of the system becomes even more critical because the user must deal not only with the constraints of the speech-recognition system but also with the constraints of the natural-language interpreter. This is particularly a problem with speech. Owing to the "naturalness" of speech, users are inclined to speak freely, forgetting any artificial constraints.

With keyboard input, users expect to be required to learn special commands and constraints to communicate. But users are often unwilling to learn any artificial constraints with speech.

PREVIOUS RESEARCH

An important concern is the degree to which syntax and vocabulary can be restricted, but still be "habitable."* To try to gain an understanding of the problem, we needed to investigate how naval officers would naturally query a database. In preliminary research, Bemis (1986) gained valuable information concerning the variability in vocabulary and syntax in questioning styles. Bemis found that naval officers will often speak tersely and use common syntactic constructions. This result was not unexpected, as naval officers are taught to speak concisely and use common terminology in all communication.

Data gathered in this initial experiment aided in assessing the requirements for a speech interface to a database. Working with ITT Defense Communications Division (ITTDCD), we developed a speech-recognition–natural language interface for a naval battle management task. In this application, natural language was used to access information in a naval taskforce database. Figure 1 shows the basic system configuration.

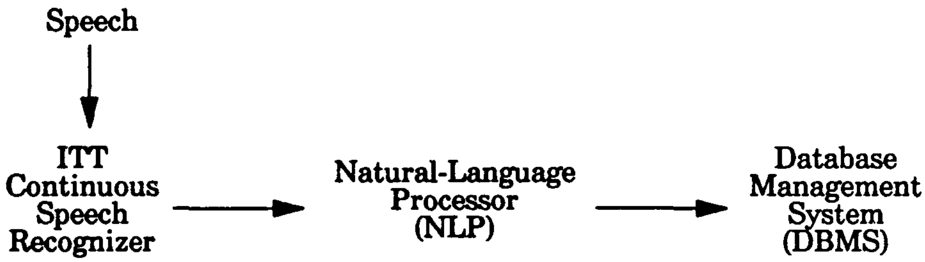

Figure 1. Speech-recognition – natural-language interface.

The ITT recognizer is a continuous, speaker-dependent, real-time system. Syntax is controlled with the use of a finite state grammar. The ITT recognizer provides high recognition accuracy and rapid training and is very robust even under high noise conditions.

The natural-language processor (NLP), developed by Janet Haake of ITTDCD, works as a keyword processor, processing and interpreting only certain words of a query. When a question is recognized, it is passed to the natural-language processor, which translates the query into the database query language commands. These commands are then sent to the Database Management System (DBMS), in this case DBASE III, which retrieves the information from the database.

The parsing procedure is described by Haake et al. (1987). The NLP parses the query one word at a time from left to right. The parsed word is looked up in a

* A habitable language is one in which the user can speak freely within a given task, but still remain within the limits set by the syntax and vocabulary.

dictionary to determine if it is a keyword. If it is found, then a particular action is triggered, based on information contained in the dictionary for that particular word. If it is not in the dictionary, i.e., if it is not a keyword, the word will be ignored, and the parser will go on to the next word in the query.

This keyword-processing approach to query interpretation has many advantages over a strict syntax-driven interpreter. The dictionary does not need to include all possible words that might occur in a query—only the keywords that carry semantic information. More important, the user has greater flexibility in structuring queries. The queries can be phrased in whatever form is most natural. In addition, the query need not even be grammatically correct. All that is necessary is for the key information-carrying words to be in the query.

LIMITATIONS

This keyword approach is very powerful and robust because (a) the task is limited and concise and there is little implied information being carried in the queries; (b) the queries are concerned only with obtaining basic information from the database; and (c) no reasoning or deduction is required to interpret the queries or retrieve the desired information from the database (Haake et al.).

The greatest limitation of this system is the speech recognizer's internal syntax. The use of keyword spotting by the NLP is not as beneficial as it could be because of the tight syntax restrictions of the recognizer. A reasonable approach would be to configure the recognizer in a word-spotting mode, thereby eliminating many of the syntax restrictions imposed by the finite-state grammar of the recognizer.

There are a number of questions concerning the feasibility of keyword spotting for a real application. The primary concern is whether the performance of the recognizer configured in the word-spotting mode will be adequate for natural-language queries. In addition, complex questions can create ambiguity for a keyword-spotting system. It is also unknown how extensive a task the keyword-spotting approach will be capable of handling.

The initial limited experiment (Bemis) generated these and many more questions. Another experiment was needed that would gather more realistic data. However, the complexity of the problem had to be limited enough to control the vocabulary used and types of questions that would be asked. An information-acquisition experiment was designed to study naval officers' natural spontaneous forms of questioning and to determine an approach to speech recognition that can best take advantage of a keyword natural-language processor. The rest of this report is devoted to that experiment.

SPEECH-RECOGNITION EXPERIMENT

METHOD

Subjects

The subjects for this study were nine naval officers currently stationed at NOSC. They had a variety of duty experiences in the Navy, but none had used speech recognition equipment before.

Procedure

The experimental sessions were conducted with each subject individually. The subjects were told that they were assisting us in the evaluation of speech recognition for use in naval command and control operations. They were also told that they would be speaking to a speech recognizer during the experiment. In reality, all questions asked by the subjects were monitored in an adjacent room by the experimenters. The subjects' questions and their answers were entered by the experimenters on their terminal and were immediately sent to the subjects' terminal.

The subjects were presented a naval scenario. They were asked a question concerning the scenario that typically could have been asked by their commanding officer. On the terminal in front of them, a blank status board was shown that represented the information available to them from a database. The subjects' task was to ask questions designed to obtain enough information to answer the question posed to them.

No restriction was placed on the vocabulary or the syntax subjects could use, except that they were told to "Ask questions to acquire information from the status board that will be displayed." There was no time limit imposed on each session.

Apparatus

The experiment was run on a Masscomp 5600 minicomputer. The task and data-collection programs were written in the C programming language by the author of this report. The subjects sat in one room and the experimenters in an adjacent room. The scenario was presented to the subjects on a WYSE 50 terminal, the same type of terminal used by the experimenters for controlling the experiment. A Panasonic WV-3400 video camera and an NV-8420 video tape recorder were used to videotape the subjects. The experimenters viewed the subjects during the experiment on a Sony 19-inch PVM-1900 color monitor. A Shure SM-10 headset microphone was used to record the subjects' speech. Figure 2 illustrates the test setup.

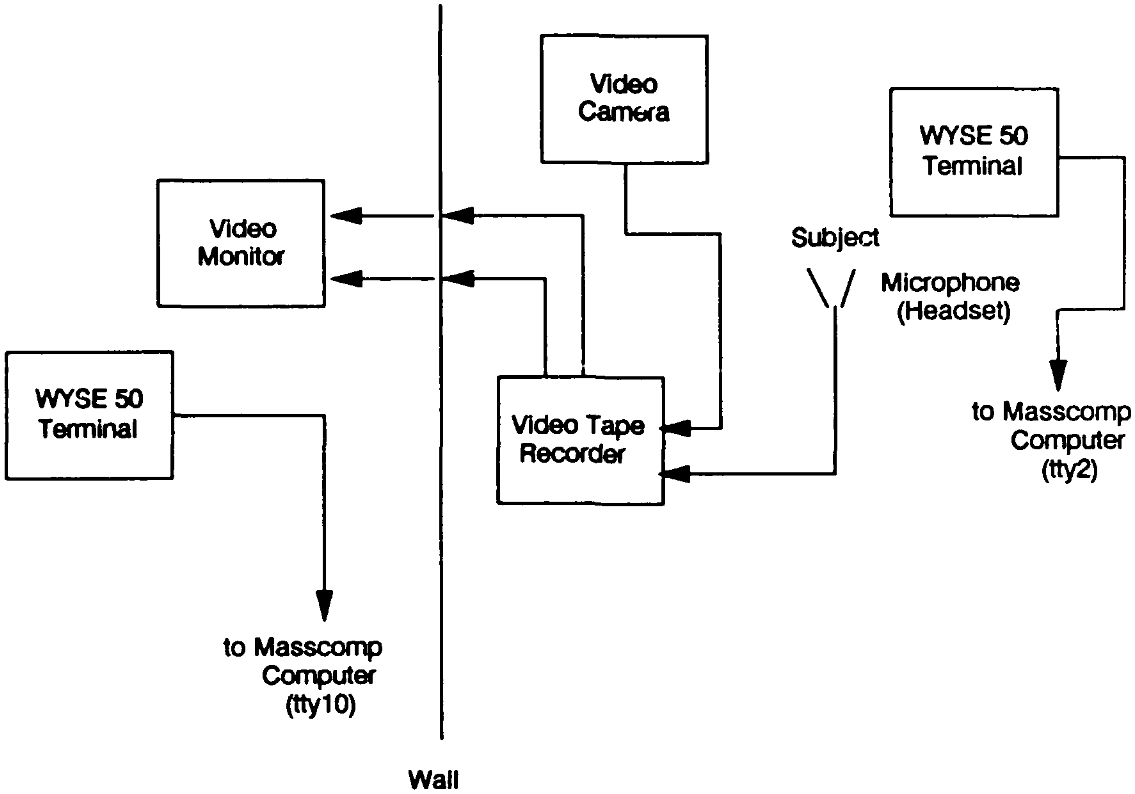

Figure 2. Experimental test setup.

EXPERIMENTAL DESIGN

There were two experimental variables in the experiment. In the first, there was complete feedback of subject queries, while in the second, feedback was restricted to only the keywords in the query. These variables were chosen to determine the degree to which the subjects' vocabulary and syntax can be shaped by feedback. It was critical to ensure that the subjects' queries would be as natural and spontaneous as possible. The approach taken was to elicit questions from the subjects by creating three simple scenarios and proceeding in the following manner:

- For each scenario, information describing the capabilities of a particular ship of interest was given as part of the subjects' instructions. The three scenarios involved the USS *Texas*, the USS *Brewton*, and the USS *Callahan*, respectively.
- The ship had some kind of problem that must be repaired.
- A question was posed to the subject concerning the problem.
- To answer the question, the subject was required to ask questions to retrieve information to "fill in" a blank status board displayed on his screen. Initially, the status board contained only information categories shown in columns across the top and available ships listed vertically along the left side of the display. (The status boards, along with each of the three

questions posed to the subjects, are presented in the appendix.) The goal of this approach of data presentation to the subjects was to avoid biasing the syntax of the questions. Although this approach would tend to bias the subjects' vocabulary, it would be biased in a natural direction for users of a database, i.e., users must have some idea of the categories of information in a database to use it at all.

- When the subject retrieved enough information, he stated his solution. The exact solution was inconsequential. The primary concern was to analyze questions framed by the subject.

- After a solution was stated, the screen cleared, and the next scenario was displayed.

Four dependent measures were used to assess subject performance:

1. *Vocabulary*. The number of keywords divided by nonkeywords was calculated for each query.

2. *Length of Queries.* Total words per query was calculated and averaged for each of the three questions.

3. *Syntactic Structures and Query Complexity*. Syntactic structures were divided into major categories. The quantity of information asked for was also examined.

4. *Unacceptable Queries.* The number of unacceptable queries was totaled for each question and for the entire session.

RESULTS

The preliminary results of the experiment showed that subjects did have their responses shaped by restricting the feedback to keywords. An analysis of variance was performed on the data. The number of keywords used compared to nonkeywords as expressed in a keyword–nonkeyword ratio was significantly higher for the restricted group. In this analysis, the larger the keyword–nonkeyword ratio, the more terse the query. The subjects in the restricted group also used significantly fewer words overall to make queries.

Vocabulary and Query Syntax Structures

The subjects' vocabulary was broken up into the following categories:

C = Command or query (classified as nonkeywords)
Q = Keyword qualifier
D = Keyword data from the status board
S = Keyword ship names or the word "ships"

All other words were considered nonkeywords and were ignored for this analysis.

Following is a list of the five most common syntactic types:

Query Type	*Example*
1. C S Q	C S Q What ships are in CENTPAC?
2. C S Q D	C S Q D What ships in the battlegroup have helos?
3. C Q S	C Q S What's the location of Wichita?
4. C Q S Q	C Q S Q How far is Kiska from Callahan?
5. C Q D S	C Q D S Is there a CASREP on the SLQ-32 on Wichita?

An analysis of syntactic types versus feedback condition revealed that restricted feedback apparently tends to limit syntax to the two simplest query forms. The following table summarizes the results:

Query Type	*% Used by Restricted Group*	*% Used by Complete Group*
1	38	1.5
2	0	7
3	57	65
4	1	14.5
5	0	5
All others	4	7

No definite conclusions can be drawn from the complete feedback data. However, it is possible that the large percentage of type-3 questions by both the restricted feedback and complete feedback groups can be attributed to the influence of their shared naval background. In the Navy, certain terms and phrases are standardized.

Amount of Information Requested

The complexity range of the questions subjects could ask was analyzed. It was decided that queries asking for information for multiple ships from a single category would be allowed, but that questions across different categories would not be allowed. This restriction is mainly due to the current capability of the natural-language processor.

Results indicated that the feedback condition had little or no effect on the amount of information requested. However, a definite trend developed in both conditions as subjects progressed from the first to the third scenario. In the first scenario, the subjects' questions were predominantly requesting only single pieces of information. By the third scenario, the majority of questions were asking for two or more pieces of information.

Unacceptable Queries

Unacceptable queries were generally of two types: (1) a correction made during or immediately following the question; (2) the question asked for multiple data items across categories. Only 6% of the total queries were considered unacceptable. No significant relationship was found between speech errors and feedback condition.

DISCUSSION

The primary goals of this study were:

1. To gain an understanding of spontaneous questioning styles used by subjects to acquire information for a problem-solving task.

2. To determine if the type of feedback presented affects the vocabulary and syntax of subjects' questions.

3. To determine if a minimal syntactic, keyword approach to speech recognition and interpretation can be used for natural-language access to a database.

VOCABULARY

The restricted-feedback condition clearly shaped subjects' queries toward the use of keywords. Subjects commented that when they realized that all the information that was needed by the speech-recognition system was the keywords, they began using the keywords predominantly. Subjects felt that the use of keywords was the quickest and easiest way to retrieve information.

For information-acquisition tasks such as database retrieval, the effect of the constraints on natural language can be minimized if the organization of the database corresponds to an organization the user perceives as natural (Ehrenreich). Given a "natural" organization to a database, subjects had little trouble accessing information using the retrieval keys or their synonyms. For example, the category "DISTANCE TO <SHIPNAME>" was listed as information directly stored in the database. This is a more natural category of information than simply storing ship-location information, which would require the user to calculate distances.

QUERY COMPLEXITY

Previous research indicates that people will tend to home in on desired information. Instead of asking for a single complex piece of data, people will request one or more simple data sets. This allows people to judge the important set relations of the data (Ehrenreich). Our results support this tendency. Subjects tended to break up the problem into small subproblems that could be solved by retrieving one piece of information or a related group of data. This approach to information acquisition also resulted in subjects asking fairly syntactically simple questions. In the restricted-feedback condition, 95% of the queries were one of the two simplest syntax forms. This supports the use of a word-spotting technique for recognition and interpretation.

When subjects found that the system could not handle a particular question, they easily rephrased it to retrieve the information they needed.

APPROACHES TO SPEECH RECOGNITION

The results of the study indicate that the use of speech recognition for natural-language access to a database is quite promising. The next question is, which approach to speech recognition would be the most effective? Current speech-recognition technology provides several choices for a speech-recognition–natural-language interface.

Isolated-Word Recognition

There are a number of applications for isolated-word recognizers in command and control operations. Several 1000-word discrete recognizers are available that work quite well. However, for applications such as database query, the requirement of speaking with distinct pauses between words is unacceptable. Isolated-word recognition works well for applications where only single commands are given, but when you allow people to speak using natural syntax and vocabulary, it is only natural for them to want to speak continuously.

Continuous Speaker-Dependent Speech Recognition

Continuous speaker-dependent speech-recognition technology has been available for the past few years. In general, acceptable performance is achieved only with very tight syntax restrictions and small branching factors. Continuous recognition systems can be configured without a syntax merely by having all words eligible at all times. The advantage of this approach is that the users do not need to remember how they must phrase questions. Unfortunately, natural language is made up of many short function words that can be very difficult to recognize when competing against each other. With current technology, even with a small-to-moderate-size vocabulary, the recognition of natural language without a syntax or language model cannot be done with acceptable accuracy.

The advantage of using a complete syntax that defines all allowable sentences is that moderate-size vocabularies with a large number of syntax nodes can be implemented while maintaining an acceptable performance level. The disadvantage is that people cannot remember specific restrictions on how sentences must be phrased. Even though the intended meaning of the question is the same and the words used may be identical, if the question does not follow the syntax, the entire question will be rejected. This would quickly lead to rejection of the system.

Keyword Spotting

The concept of keyword spotting relies on the idea that, for certain applications, only keywords will be necessary to communicate the intended meaning of a sentence. This use of keyword spotting is quite different from the conventional use of word spotting, where the goal is to survey large amounts of information taken from noisy radio links having narrow bandwidths and to select conversations about topics

of special interest. These conditions make the task of word spotting difficult, because the speaker is generally unknown, the channel distorts and adds noise, the conversation vocabulary and syntax are unlimited, and the speech can be sloppily spoken (Lea, 1981). In these conventional applications, the approach to word spotting is to choose appropriate word and subword vocabularies to compete with the keywords to be recognized.

Research in word-spotting techniques indicates that the performance of a word spotter is greatly influenced by the number of filler or nonkeyword templates. In particular, the number of filler templates and their duration are the critical parameters. As the number of fillers is increased or their duration is decreased, the probability of false alarm decreases, but so does the probability of detecting the correct keyword. The effect of adjusting these parameters is analagous to varying the rejection threshold of a recognizer (Higgins and Wohlford, 1985).

The approach of keyword spotting for database query is substantially different than for conventional word-spotting applications. There are a number of aspects of the database query application that would greatly increase the performance of the keyword-spotting technique. The system would be speaker-dependent, and most of the nonkeyword vocabulary would be known. Results of the experiment indicate that, in general, users will ask fairly syntactically simple questions. The vocabulary used will be restricted by the users' knowledge of the functions the system can perform (in control operations) and the kind of information available (for database access). At the acoustic level, information-carrying keywords are prominently stressed and clearly articulated. This tends to minimize many of the problems associated with continuous speech (such as coarticulation and missing segments of speech).

However, there are potentially serious drawbacks to using keyword spotting. The context of the words is not known and cannot be used to reinforce or verify decisions. Syntactically complex questions, in general, cannot be handled. The key to minimizing these problems is that keyword spotting relies on another piece of information—semantic knowledge, or intended meaning. The natural-language processor does not have to know the interpretation of a word in all possible contexts, because the user will have basic knowledge of what information is available before using the system. It is not unreasonable to require the person using the database to know what kind of information is in the database.

CONCLUSIONS

Feedback appears to be a powerful technique for controlling the vocabulary and, to some extent, syntax of queries. It was originally thought that the effect of using only keywords for feedback would occur slowly over time. However, the effect can be seen almost immediately in subjects' queries.

Given a task whose "solution set" is limited to data that can be represented in a tabular format corresponding to what users conceive of as natural for the task, users will ask syntactically simple queries gathering small pieces of data at a time.

Restrictions imposed by a natural-language interpreter on query complexity is not offensive to users. Syntactically simple queries seem to be preferred. As long as

users feel no restrictions on how to ask for information, the complexity of queries is not an issue.

Categories of information presented as headings to subjects produce an overwhelming tendency to use these keyword categories. However, subjects will also use synonymous terms, depending on their approach to solving the problem.

A number of subjects found keywords to be preferred over complete natural-language sentences. Their interaction was very much goal driven; therefore, only the vocabulary necessary to communicate the desired information was used.

RECOMMENDATIONS

It became apparent that more problem-solving tasks were needed to allow subjects to test the capability of the system. With more problems, it may be that people will ask for more information per query. If each problem requires much of the same information, people will get frustrated with asking for only one piece of information.

The table data-presentation format may have constrained the complexity of questions people would ask. Available information should be presented as a list of database categories. In addition, to be as realistic as possible, retrieved information should be displayed in a table.

The extent to which current speech-recognition technology can be used for natural-language database access depends on the number of restrictions imposed on the user. Increased vocabulary size may facilitate natural speech interaction. However, syntactic restrictions predominate the speech interaction long before the vocabulary reaches 100 words (Schmandt, 1986).

In preliminary tests with the ITT recognizer configured in a word-spotting mode, results appear very promising. Further experiments in real and simulated command and control situations will be necessary to answer remaining questions.

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Appendix A

STATUS BOARDS SHOWING THE THREE SCENARIOS

AVAILABLE SHIPS IN CENTPAC
STATUS BOARD

SHIP	CLASS	SPEC. EQUIP.	CASREPS	DISTANCE TO TEXAS	MAX SPEED
JOUETT					
HORNE					
WAINWRIGHT					
YORKTOWN					

Q1: Which available ships could replace Texas?

QUESTIONS?

AVAILABLE SHIPS IN CENTPAC
STATUS BOARD

SHIP	CLASS	SPEC. EQUIP.	CASREPS	DISTANCE TO TEXAS	MAX SPEED
MEYERKORD					
PATTERSON					
REASONER					
BRONSTEIN					

Q2: Which available ships can replace Brewton in the shortest amount of time?

QUESTION?

AVAILABLE SHIPS IN CENTPAC
STATUS BOARD

SHIP	CLASS	SPEC. EQUIP.	CASREPS	DISTANCE TO TEXAS	MAX SPEED
BUCHANAN					
CHANDLER					
NICHOLSON					
BERKELEY					

Q3: Can any ship replace Callahan before her SLQ-32 is replaced?

QUESTION?